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SELECTION OF ADDITIVE MANUFACTURING (AM) EQUIPMENT

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13. ABSTRACT (Maximum 200 Words)
Recent advancements in technology have enabled Additive Manufacturing (AM), also known as Three-Dimensional (3-D) printing, to become a powerful, viable tool in the research, development, and overall engineering of many products in the world today. This report will give an overview of the selection of AM equipment for the United States (U.S.) Army Aviation and Missile Research, Development and Engineering Center (AMRDEC) to use as a tool in the design, test, and fabrication of the systems within the AMRDEC portfolio.

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EXECUTIVE SUMMARY

Additive Manufacturing (AM) has advanced exponentially since the mid-1980s. The United States (U.S.) Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) has been tracking AM over recent years and is considering investing in AM machinery to fill the current capability gap from other Research, Development, and Engineering Centers (RDECs) and other government entities. This report gives a brief synopsis of the background in AM by Subject Matter Experts (SMEs) tasked with choosing the machinery, an overview of the capabilities of each machine, and the rationale for selecting each specific machine.

The Science and Technology (S&T) program included opportunities for AMRDEC personnel to work in other Government laboratories, such as National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) and Oak Ridge National Laboratory (ORNL) Manufacturing Demonstration Facility (MDF). The increased exposure to the vast number of additive technologies and machines and also to the inner workings of the respective machines greatly influenced the decision process. Having the ability to be exposed to the various machines and how each machine differs also greatly influenced the decision process to provide the best fit for how AMRDEC anticipates using the equipment. Input from other Army Research, Development, and Engineering Command (RDECOM) laboratories greatly influenced the decision process as the other laboratories, that is, Army Research Laboratory (ARL), Army Armament Research, Development, and Engineering Center (ARDEC), and so forth, had valuable insight to new technologies that had not been released to the general public. The laboratories currently have Cooperative Research and Development Agreements (CRADAs) and other agreements with the machine vendors to share information prior to release to the public. This information was critical in keeping the machine selection relevant for the upcoming years:

- Hybrid Blown-Powder System
    - DMG Mori Lasertec 4300 3D
    - Features a blown-powder deposition head inside of a typical multi-axis machining center to greatly increase the capability over two separate machine tools
- Laser Powder Bed System
    - 3D Systems ProX 320 DMP
    - Features the ability to fabricate highly complex parts that could not be fabricated traditionally
- Hybrid Multifunctional
    - nScrypt
    - Features the ability to print various materials using various processes in a multihead delivery system with integrated metrology equipment

EXECUTIVE SUMMARY (CONCLUDED)

- Training/First Level Prototyping
    - Stratasys 250MC FDM
    - Features an easy-to-use, almost foolproof, platform to train the AMRDEC workforce and to prototype parts prior to using a more expensive machine/material, that is, the ProX or Lasertec

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I. INTRODUCTION

Additive Manufacturing (AM) has become a very powerful technology in recent years due to advancements in various technologies such as lasers and control systems. The United States (U.S.) Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) has been slow to adopt these AM technologies in the day-to-day operations of the engineering workforce. AM has several benefits, such as decreased fabrication time and/or cost, increased performance, and ability to test multiple design iterations quickly. As of the time of writing, there are seven classifications of AM technologies according to American Society for Testing and Materials (ASTM). AMRDEC currently has three of the technologies in-house. These technologies are typically used only for rapid prototyping, however, and do not allow for fabrication of structural components for testing in a system. AMRDEC has shown interest in obtaining the AM technologies to fill the capability gap. As part of the AM for Missile Components Science and Technology (S&T) program, AMRDEC surveyed various machine vendors, AM-based part vendors, other government agencies, and attended various conferences to aid in the selection process of the machines that could be used to fill the capability gap and serve AMRDEC as a whole.

AMRDEC uses the Stratasys Objet system, several Fused Deposition Modeling (FDM) type systems and small Stereo Lithography (SLA) systems, as shown in Figure 1. Most systems are desktop and hobby-level equipment that are being used as powerful tools in the design and development of AMRDEC products.

Figure 1. Stratasys Objet Connex3 [1]

While these machines and technologies have specific uses at AMRDEC, the materials that are used are not typically suitable for use in aviation or missile systems, as shown in Figure 2. The need for the ability to print metallic structures will be paramount in future years if AMRDEC is to remain relevant.

Figure 2. Accelerometer Bracket Designed Using Topology Optimization and Fabricated Using Direct Metal Laser Sintering Technology

II. BACKGROUND

The S&T program included opportunities for AMRDEC personnel to work in other Government laboratories, such as National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) and Oak Ridge National Laboratory (ORNL) Manufacturing Demonstration Facility (MDF). The increased exposure to the vast number of additive technologies and machines and also to the inner workings of the respective machines greatly influenced the decision process. Having the ability to be exposed to the various machines and how each machine differs also greatly influenced the decision process to provide the best fit for how AMRDEC anticipates using the equipment. Input from other Army Research, Development and Engineering Command (RDECOM) laboratories greatly influenced the decision process as the other laboratories, that is, Army Research Laboratory (ARL), Armament Research, Development and Engineering Center (ARDEC), and so forth, had valuable insight to new technologies that had not been released to the general public. The laboratories currently have Cooperative Research and Development Agreements (CRADAs) and other agreements with the machine vendors to share information prior to release to the public. This information was critical in keeping the machine selection relevant for the upcoming years.

III. AMRDEC CAPABILITY GAPS IDENTIFIED

An informal survey of the AMRDEC workforce was used to identify the gaps that should be filled initially. The AMRDEC portfolio consists of a large assortment of technical areas from basic research to sustainment of programs and thus provided a challenge to fill those needs with a small number of machines. Since AMRDEC already owned several polymer based machines, metal printing was priority for choosing a new set of machines. There are several technologies for metal printing, and the next step was to choose which types should be purchased. It was decided that two types of machines would benefit the majority of AMRDEC: blown-powder and powder-bed systems. The blown-powder systems are typically use to fabricate larger near-net shaped components that require machining afterwards to bring the part into specification and are also used in various repair applications. The powder-bed systems are used for smaller components that contain a larger degree of complexity or require a higher degree of precision over the blown-powder systems. These two systems complement each other in capabilities. The third system was chosen to support the electronics/sensor/communications functional groups and has the ability to incorporate electrical conduction paths into a polymer structure.

IV. CANDIDATE MACHINES

A. Hybrid Blown-Powder System

Blown-powder systems consist of a nozzle with an integral energy source. Lasers are the preferred source for melting the metal powder that is blown through the nozzle into the beam at the application point. This method is useful for larger components as this delivers the material relatively quickly but at reduced resolution compared to the laser power-bed systems.

The DMG Mori Lasertec 4300 3D was selected for the blown-powder system, as shown in Figures 3 and 4. Note that in Figure 4 that the machined surfaces were previously deposited. There are two viable candidates that offer a blown-powder additive capability incorporated into a typical multi-axis subtractive machining center. The hybrid approach is gaining interest in the traditionally subtractive machine tool industry as the additive technologies are being accepted and implemented in many machine shops. The advanced technology and software integration of the DMG Mori system vastly exceeds the capabilities and technology level of the competitor.

Figure 3. DMG Mori Lasertec 4300 3D [2]

Figure 4. DMG Mori Lasertec System Depositing Metal Powder Onto Part [3]

The Engineering Directorate Manufacturing Technology division has been tracking this type of additive technology in various programs as a suitable method for repairing aviation parts that are out of specification for various reasons. The ability to add material that has been worn away from use has the potential to save the aviation project offices a substantial amount of money by repairing the worn surfaces instead of purchasing new parts for replacement. While the AMRDEC machine would not be used to repair the parts, the processes and material characterization would be performed at AMRDEC and then transitioned to a contractor. The Tank Automotive Research, Development and Engineering Center (TARDEC) has shown success in repairing various components of the M1 Abrams tank using blown-powder deposition and subsequent machining.

The system has demonstrated the ability to produce high-quality, complex pressure vessels that are of interest to the missile-oriented directorates also and would be used to fabricate concept demonstration articles for the various S&T projects of AMRDEC.

B. Laser Powder Bed

Powder-bed systems typically consists of a build vat, feedstock hoppers, a material spreading device, and an energy source. The material spreading device, usually a blade, retrieves material from the hoppers and spreads it evenly across the build vat where it is melted by the energy source. The two most common energy sources are lasers and electron beam, as shown in Figures 5 and 6.

Figure 5. 3D Systems ProX DMP 320 [4]

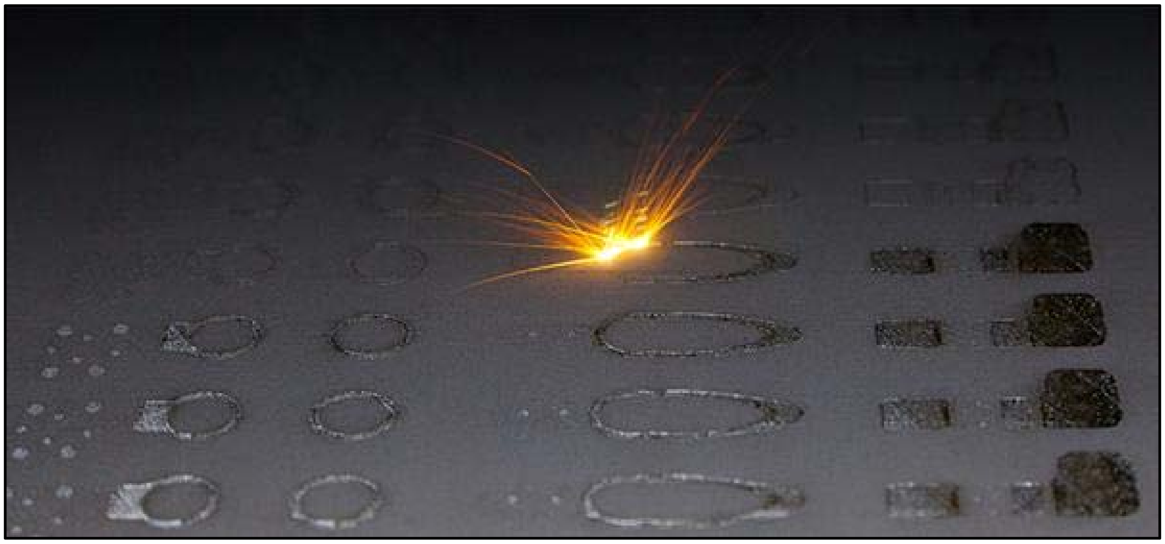

Figure 6. Laser Melting Metal Powder [5]

Powder-bed processes lend themselves to fabrication of highly complex shapes that are either very difficult or impossible to fabricate with traditional methods, as shown in Figure 7. The powder-bed systems are limited to smaller build envelopes because the entirety of the bed must be filled with metal powder. Simply filling the machine for the first build may require $10,000-$50,000 worth of metal powder, but in many cases, the powder can be reused in subsequent build operations and thus the cost per build is reduced.

Figure 7. Complex Lattice Structure [6]

AMRDEC's work in topology optimization relies heavily on the laser powder-bed systems to fabricate the complex, organic geometries generated by the software. The topology optimized structures feature reduced weight or other benefits defined in the optimization routines.

C. Hybrid Multifunctional

The quest for higher performance aviation and missile systems has driven efforts of integrating the electrical systems into the structural components or conversely using the structural components as electrical conductors. The additive world has previously been segregated into two areas, structural and functional, meaning components that have no real structural use but fulfill some functional purpose such as a circuit board or sensors. There has been an increase in machines that perform in functional and structural areas. These machines typically will print a polymer structure with included printed circuitry by means of conductive inks. This methodology could be beneficial by reducing part count in a system or making valuable physical volume available for other components. For example, a circuit card that previously occupied space in a missile is reconfigured and printed on the airframe, thus vacating space for a larger warhead.

The nScrypt machine incorporates high-accuracy positioning stages, high-accuracy deposition heads, and high-resolution vision devices to fabricate high-quality, novel items that previously were impossible to manufacture, as shown in Figures 8 and 9.

Figure 8. nScrypt Multi-Functional Machine [7]

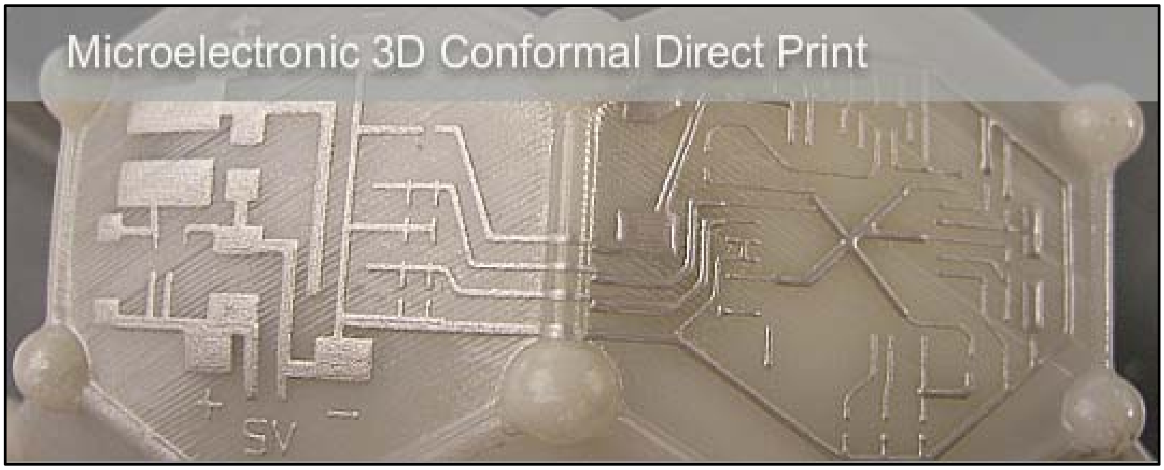

Figure 9. Hybrid Structural/Functional Demonstration Part [8]

V. TRAINING

Perhaps the most important function of the AM facility is to educate AMRDEC engineers and scientists concerning AM and removing some of the design barriers that have been in place for years. Machines are advancing at an amazing rate, incorporating new and better technologies, but if the engineers are not educated in how to use the new technologies, then the benefit is lost.

The rest of the world, including nations that are considered unfriendly to the U.S., is advancing weaponry by using additive technologies, and AMRDEC cannot be behind these countries simply because engineers do not have access to the tools.

The Stratasys 250MC FDM machine was chosen for training machines and to fabricate prototypes prior to printing in metal. The machines are easy to learn and provide engineers with the foundation of Three-Dimensional (3-D) printing. They typically produce consistent results as the materials and processing parameters are locked down and cannot be altered by someone who does not properly understand the process and how various parameters influence produced results.

Figure 10. Stratasys 250MC FDM Machine [9]

VI. CONCLUSION

It will be the mission of the AMRDEC AM facility to train the local workforce, provide access to AM technologies, and generate scientific contributions to further AM technology. The center will provide a foundation for opening the design space and creativity of the workforce to better equip Soldiers on the battlefield when needed. The work performed at AMRDEC will eventually aid the expeditionary AM efforts as a proving ground and a knowledge center.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

3-D, 3D	Three-Dimensional
AM	Additive Manufacturing
AMRDEC	Aviation and Missile Research, Development, and Engineering Center
ARDEC	Armament Research, Development, and Engineering Center
ARL	Army Research Laboratory
ASTM	American Society for Testing and Materials
CRADA	Cooperative Research and Development Agreement
DMLS	Direct Metal Laser Sintering
FDM	Fused Deposition Modeling
MDF	Manufacturing Demonstration Facility
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
ORNL	Oak Ridge National Laboratory
RDECOM	Research, Development and Engineering Command
S&T	Science and Technology
SLA	Stereo Lithography
SME	Subject Matter Expert
TARDEC	Tank Automotive Research, Development, and Engineering Center
U.S.	United States